Impedance Eduction in Three-Dimensional Sound Fields with Peripherally Varying Liners

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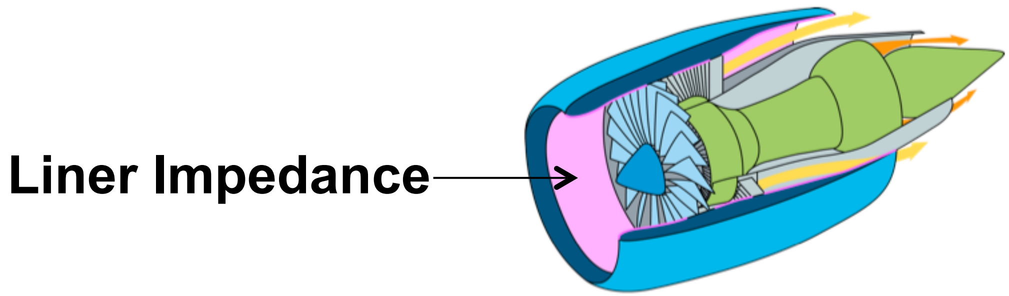
Motivation (Fan Noise Reduction)



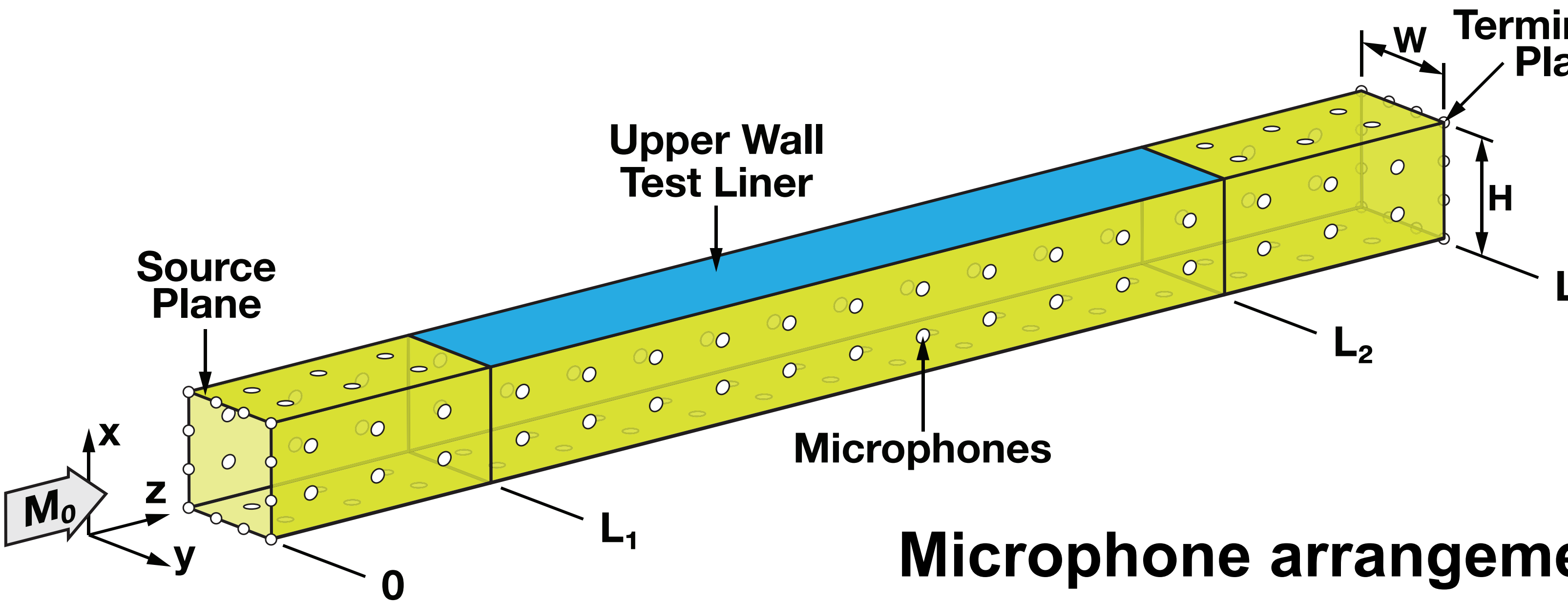
- Liner impedance is a critical input parameter
- For at least two decades the NASA Langley Research Center has been developing tools for impedance eduction
  - Account for uniform or sheared flow profiles in the duct
  - Successfully applied to liner samples in the GFIT and CDTR
- Limitations:
  - Applicable only to 2D or quasi-3D sound fields
  - Not applicable to ducts with peripherally varying impedance

Research Objectives

- To develop an impedance eduction code that
  - Accounts for 3D sound fields
  - Accounts for peripherally varying wall impedance
- To validate the 3D code using measured GFIT data by
  - Comparing 3D results to that educed from the 2D code
  - Comparing results of a peripherally varying three-segmented liner to that of a known impedance spectra

Measurement Apparatus

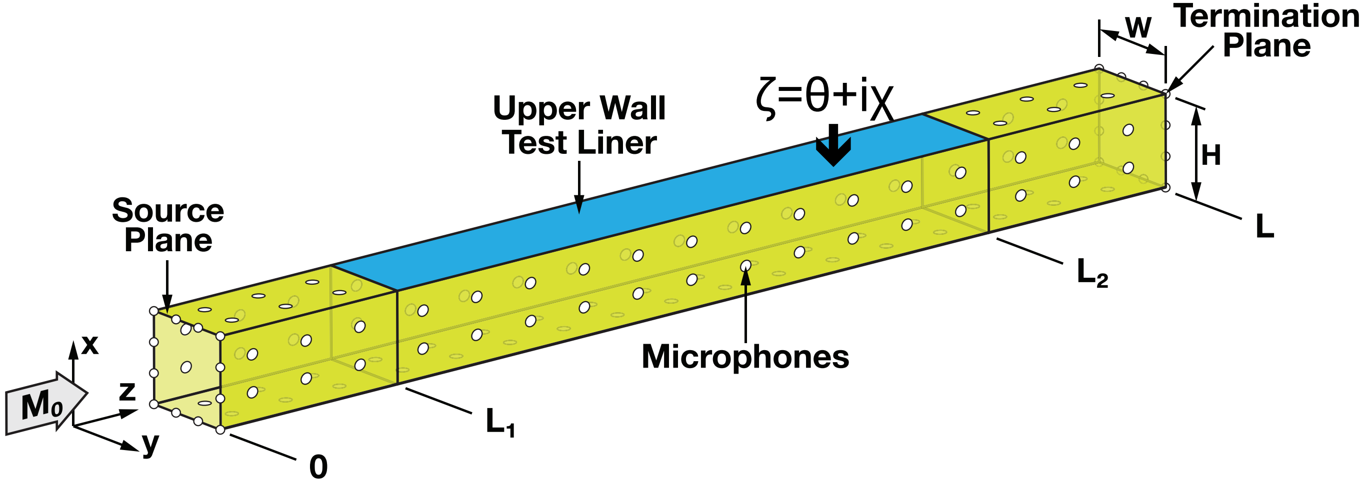
GFIT and Instrumentation



Microphone arrangement for 3D Impedance Eduction

$$W = 2.0'', H = 2.5'', L_1 = 8.0'', L_2 = 32.0'', L = 40.0''$$

Boundary Value Problem



- Solve the convected Helmholtz's Equation

$$(1-M_0^2)\frac{\partial^2 p}{\partial z^2}+\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}-2ikM_0 p+k^2 p=0$$

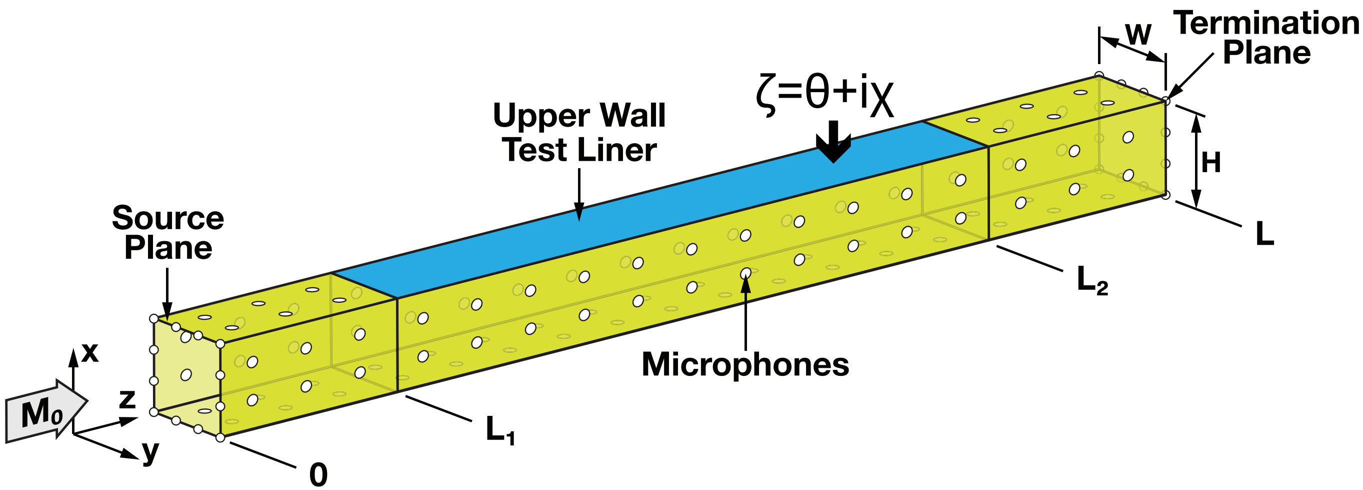
- Use the source/exit plane pressures as inflow/outflow BC's

$$p(z,x,y)\,|_{z=0}= p_s(x,y);\quad p(z,x,y)\,|_{z=L}= p_E(x,y)$$

- The Myers wall impedance boundary condition along the liner

$$\frac{\partial p}{\partial n}=ik\left(\frac{p}{\zeta}\right)+2M_0\frac{\partial}{\partial z}\left(\frac{p}{\zeta}\right)+\frac{M_0^2}{ik}\frac{\partial^2}{\partial z^2}\left(\frac{p}{\zeta}\right)$$

Impedance Eduction



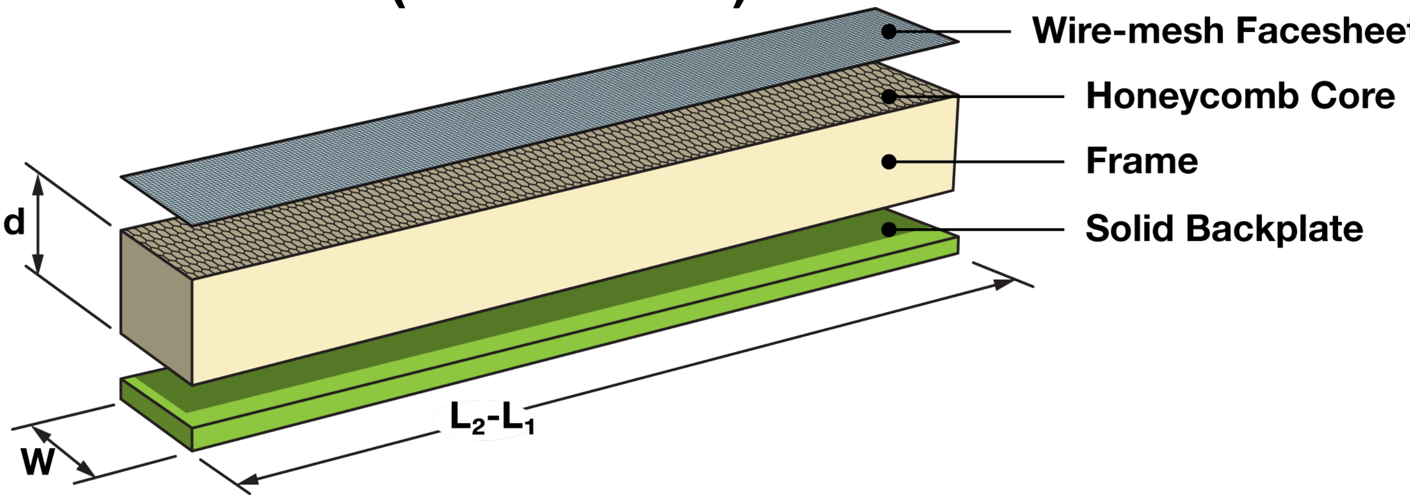
- Solve the 3D boundary value problem using the finite element method (FEM) and obtain the acoustic pressure field, p
- Construct the quadratic objective function, F(θ,χ)

$$F(\vartheta,\chi) = \sum_{m=1}^{m=nmic} \| p_{Meas}(z_m, x_m, y_m) - p_{FEM}(z_m, x_m, y_m) \|$$

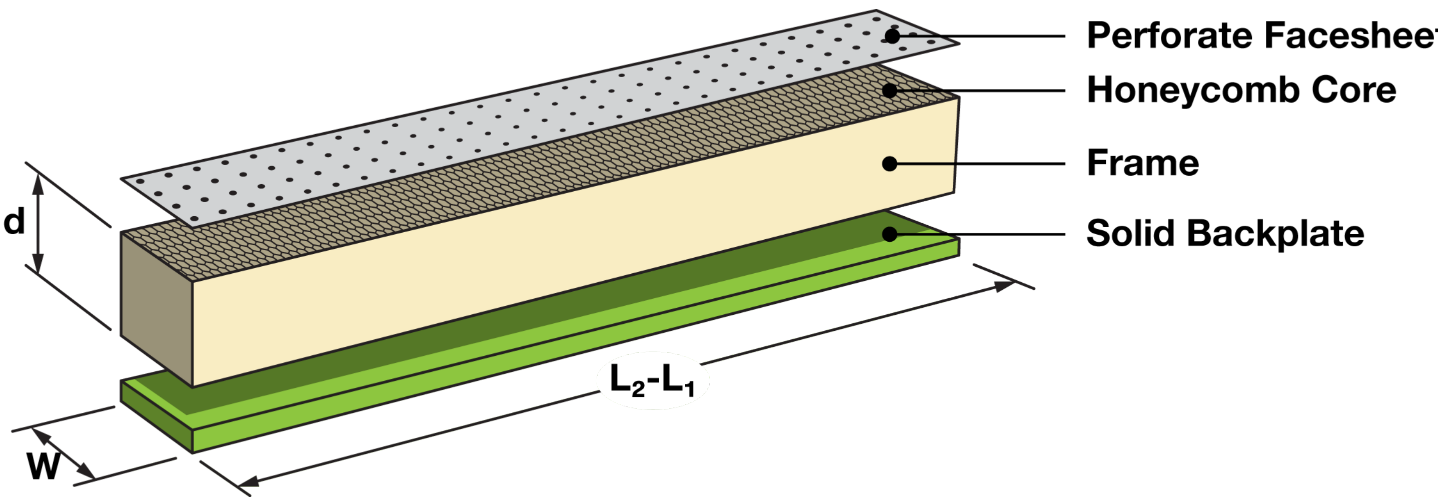
- Find the Minimum of this objective function using a local gradient-based optimizer to obtain the unknown impedance

Uniform Test Liners

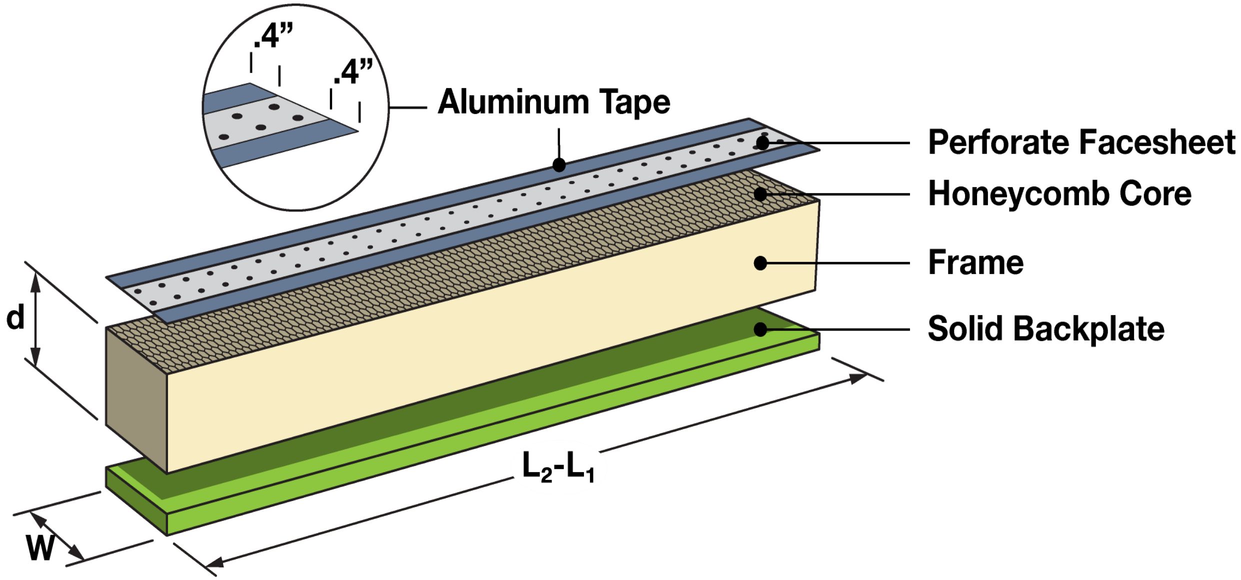
Wire-Mesh Liner (linear liner)



Conventional Liner (nonlinear liner)

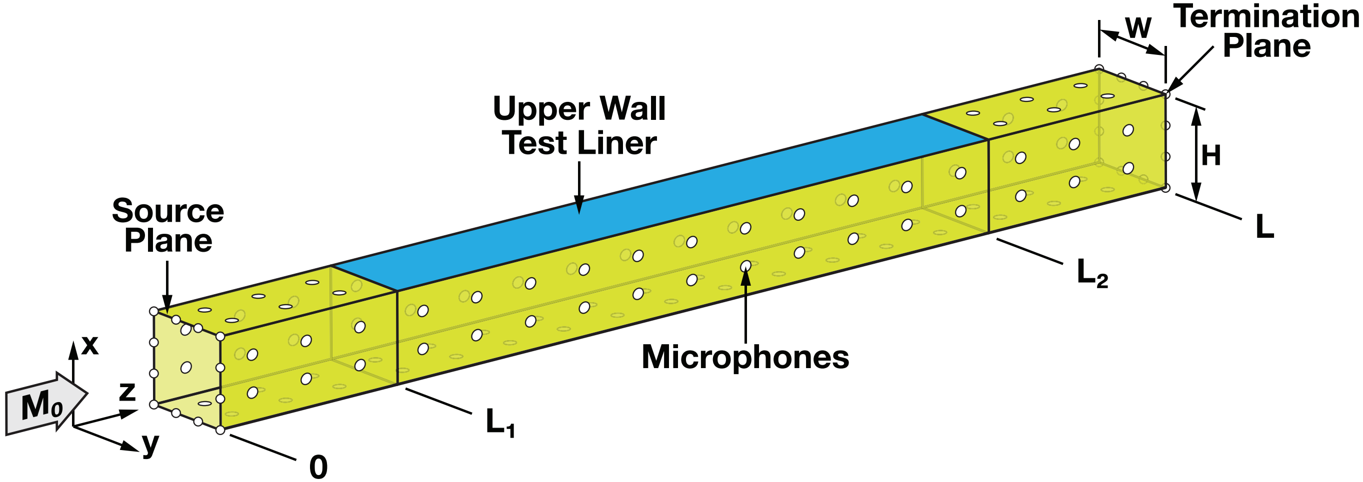


Peripherally Varying Liner



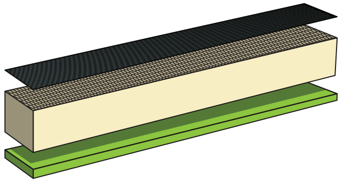
- Scatters energy into spanwise duct modes (3D effect)
- Impedance of aluminum tape is set to that of a rigid wall
- The impedance of the soft segment is identical to that of the conventional liner
- Same liner is being tested by the French aerospace company (ONERA) using Laser Doppler Anemometry

Test Conditions

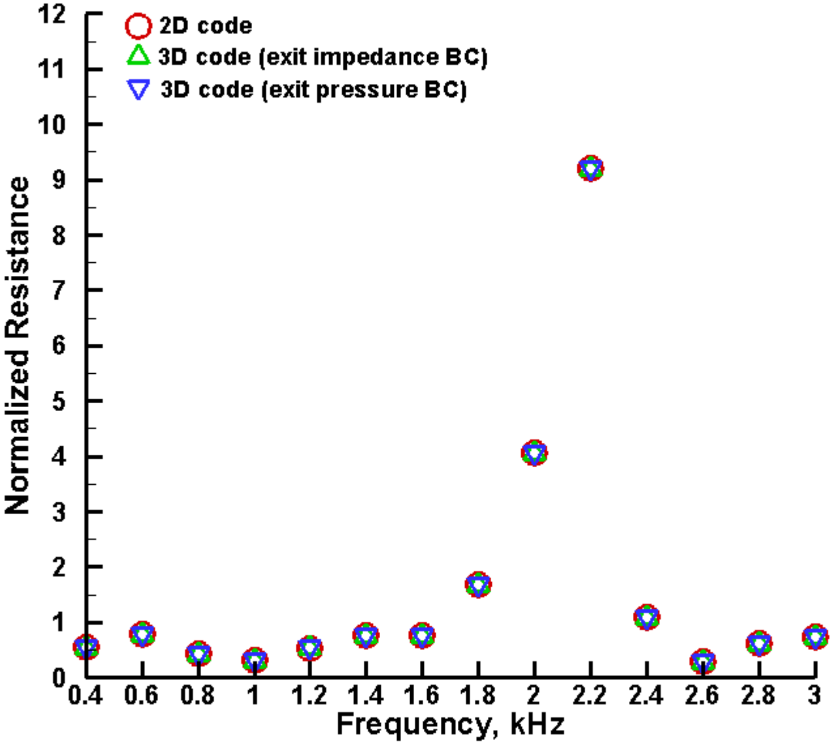


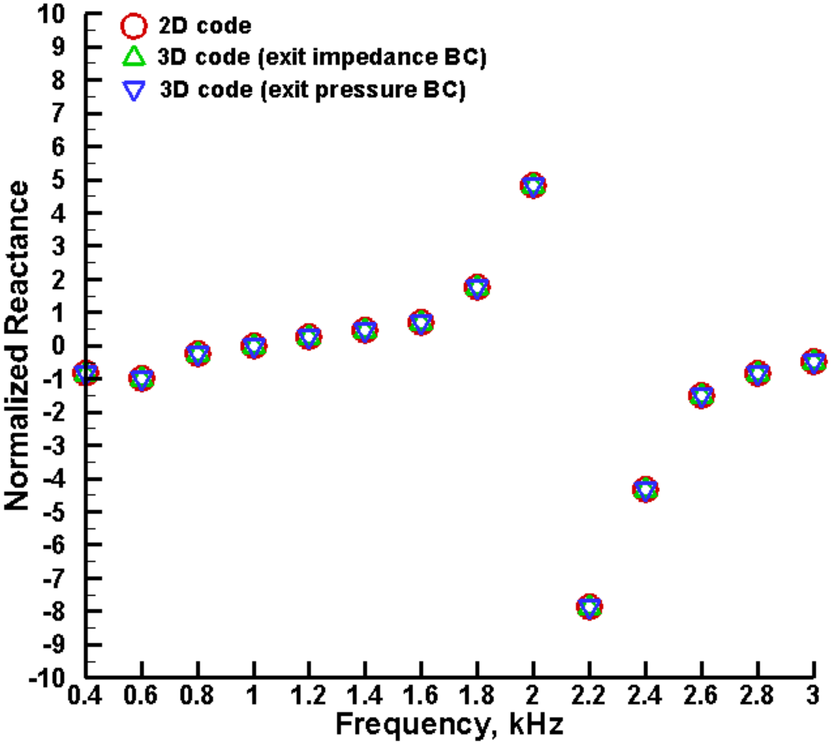
- Data acquired in the GFIT (2 inch x 2.5 inch cross-section)
- Each liner (wire-mesh and conventional) is 24 inches long
- Three uniform flow Mach numbers
  - Wire mesh liner (Mach 0.0, Mach 0.3, Mach 0.5)
  - Conventional liner (Mach 0.0, Mach 0.2, Mach 0.3)
- Frequency range of interest, f=0.4 to 3.0 kHz
- Data acquired at 87 microphones around duct perimeter

Comparison of 2D and 3D Codes (Mach 0.5)



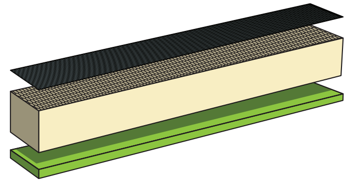
Microphone data acquired from exact mode solution



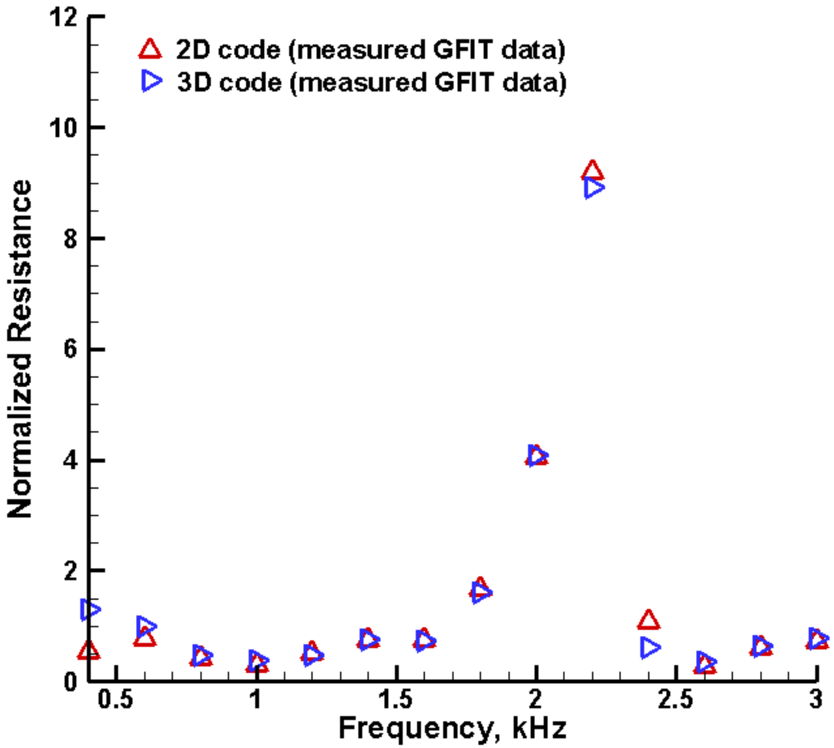


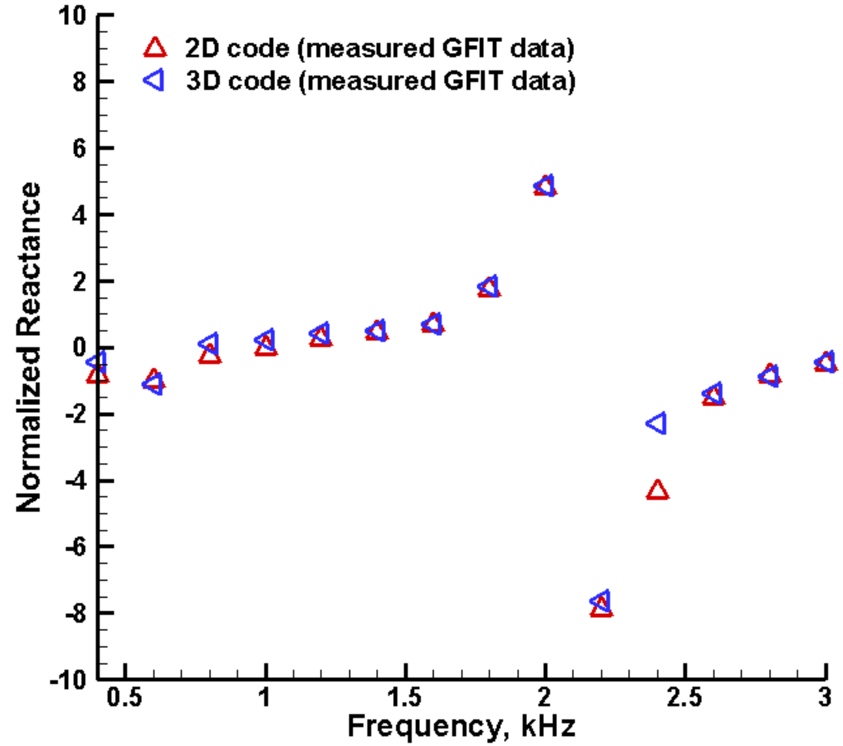
✓ 2D and 3D codes are in excellent agreement

Comparison of 2D and 3D Codes (Mach 0.5)



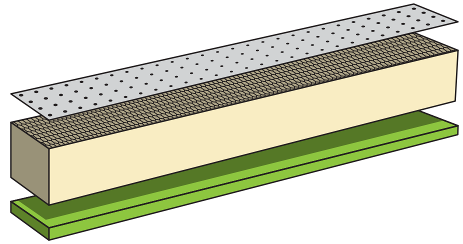
Microphone data measured in the GFIT



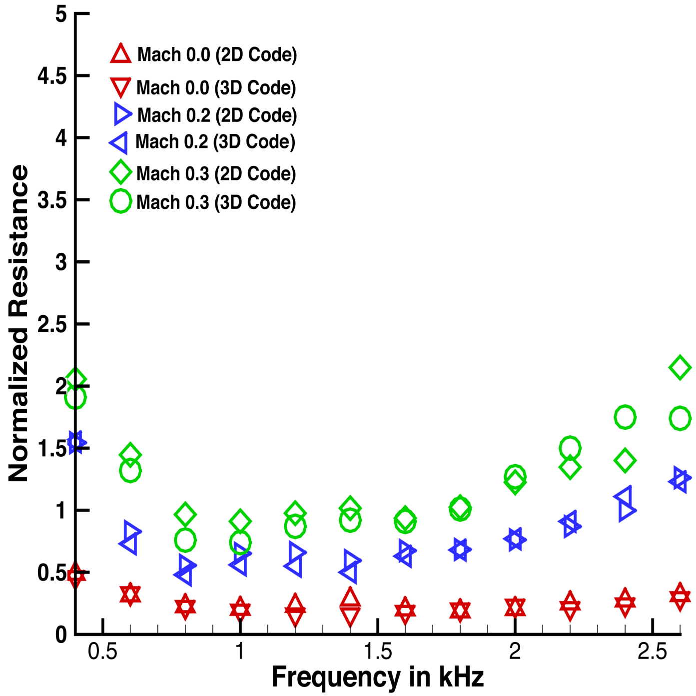


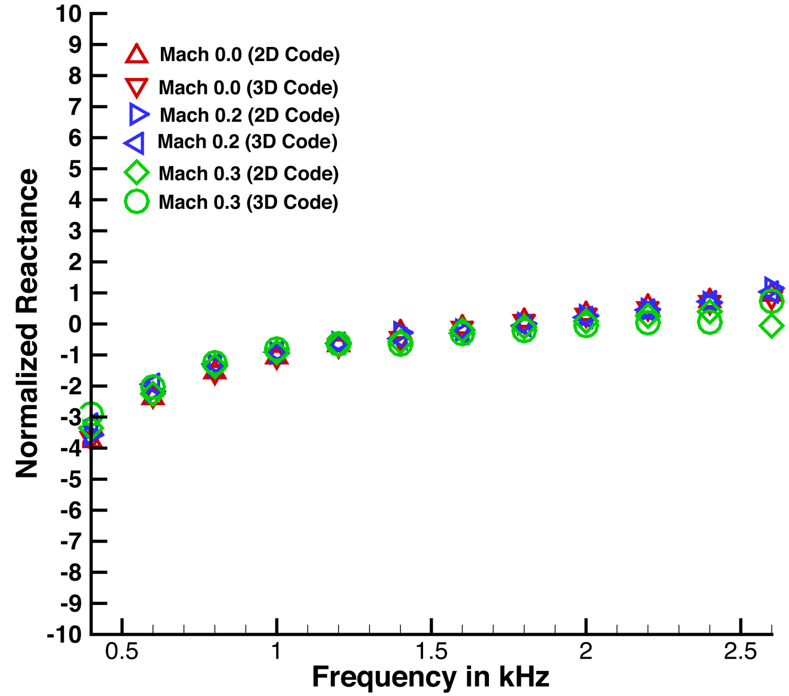
✓ 2D and 3D codes are in excellent agreement except at frequencies of low attenuation

Comparison of 2D and 3D Codes



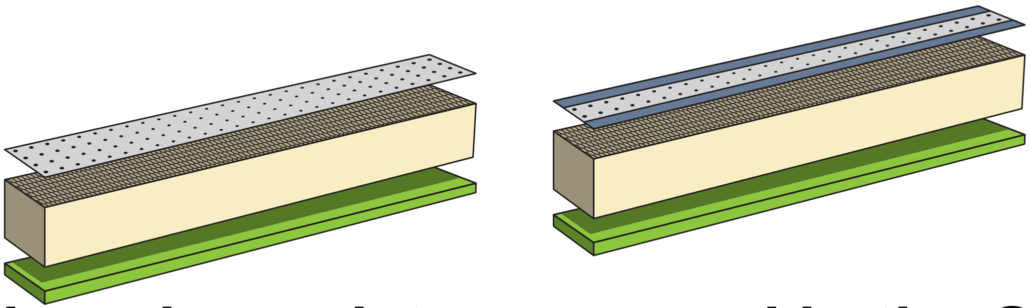
Microphone data measured in the GFIT



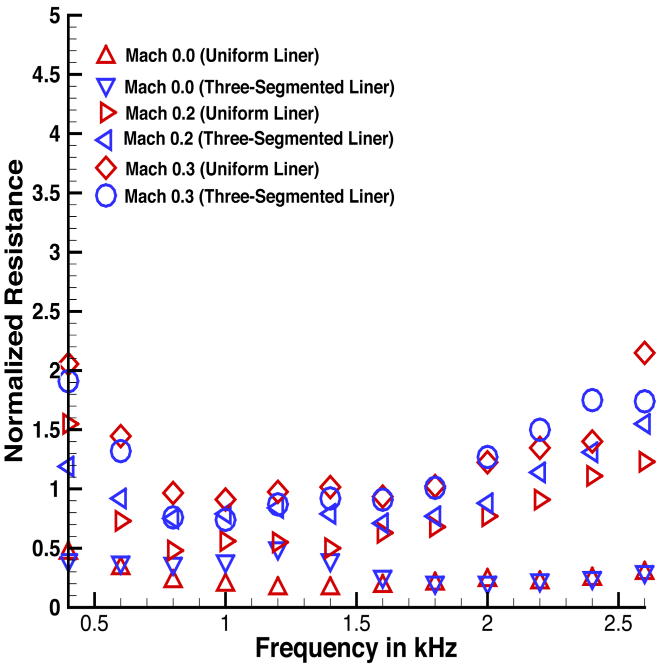


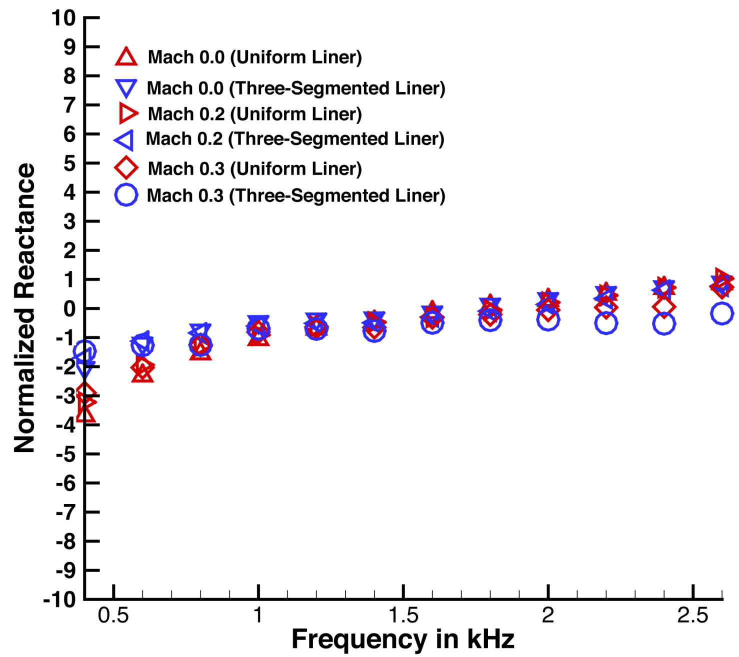
- ✓ 2D and 3D Codes are in excellent agreement except at resonance and frequencies above cuton of higher order modes

Comparison of Uniform and Segmented liner



Microphone data measured in the GFIT



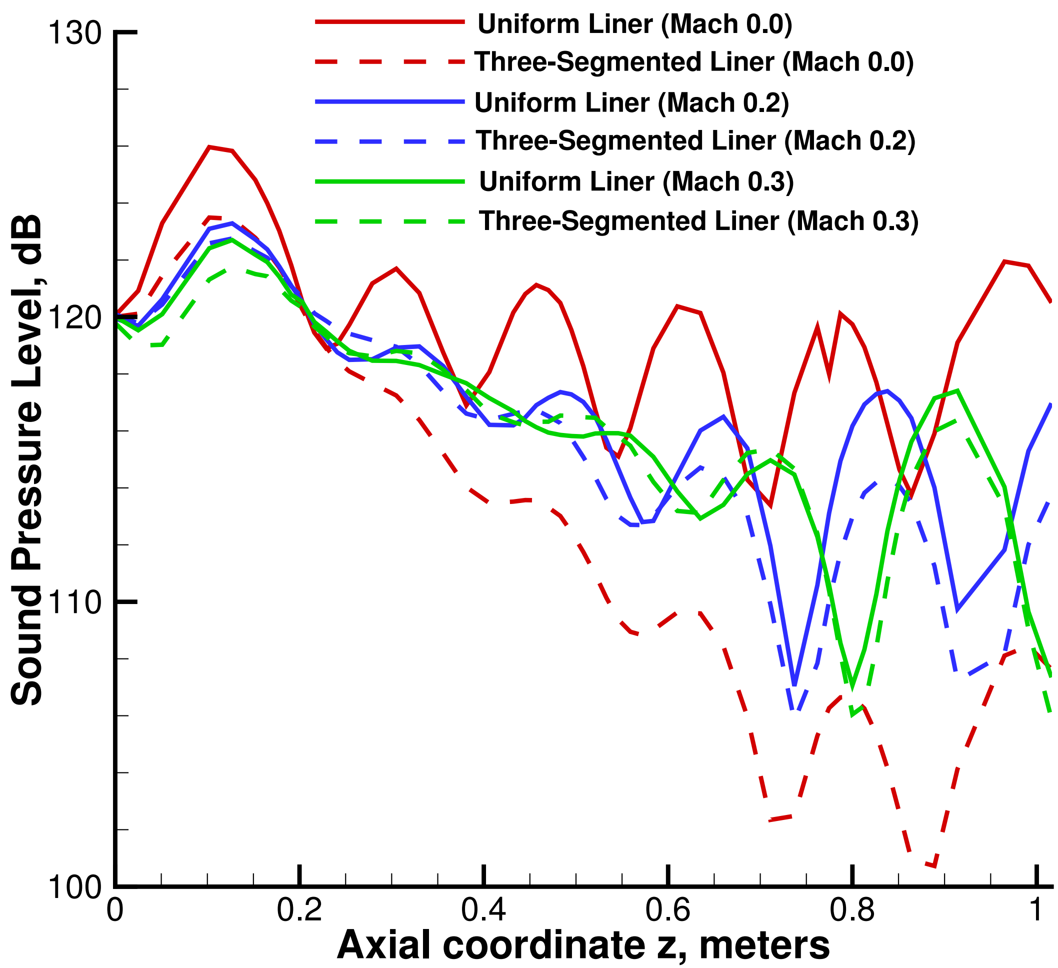


✓ Impedance of uniform and soft segment of three-segmented liner are in good agreement

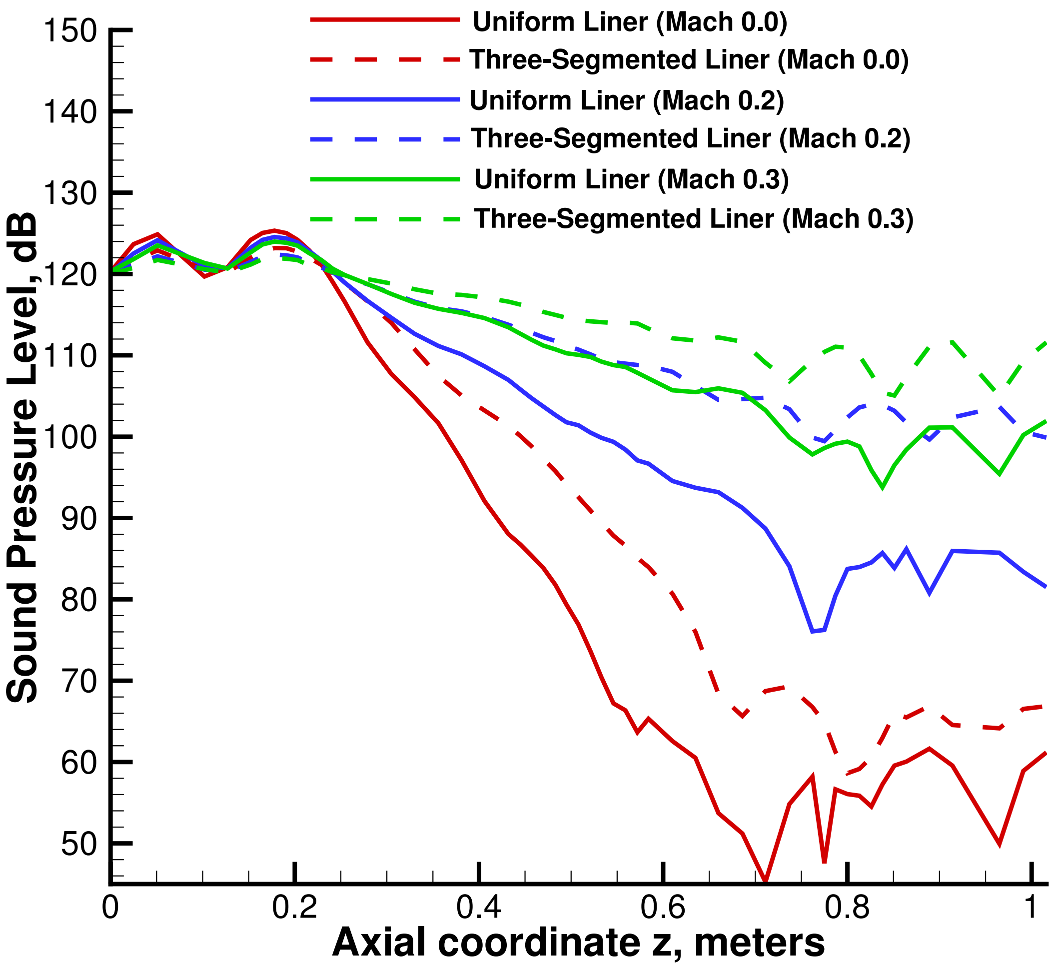
Conclusions

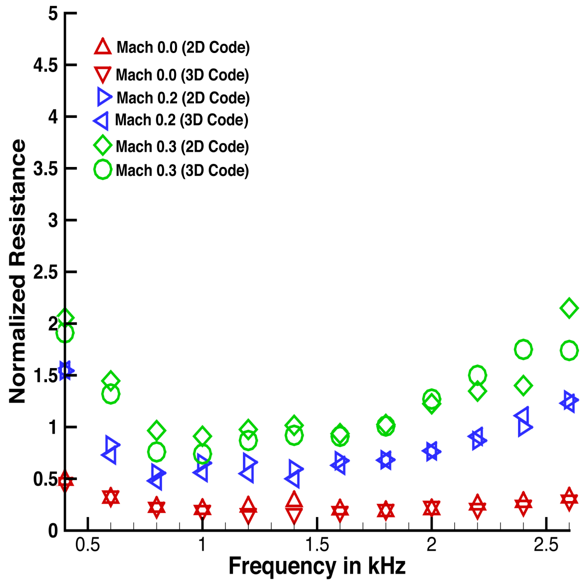
- The current 3D method educes the impedance spectra to design order with exact input data
- When GFIT data is used with the uniform-structure test samples, the 3D theory reproduces the same impedance spectra as the 2D theory except for frequencies corresponding to very low or very high liner attenuation
- When the educed impedance of the uniform-structure liner is compared to that of the soft portion of the three-segmented liner, good agreement is generally obtained except for those frequencies corresponding to extremely large attenuation

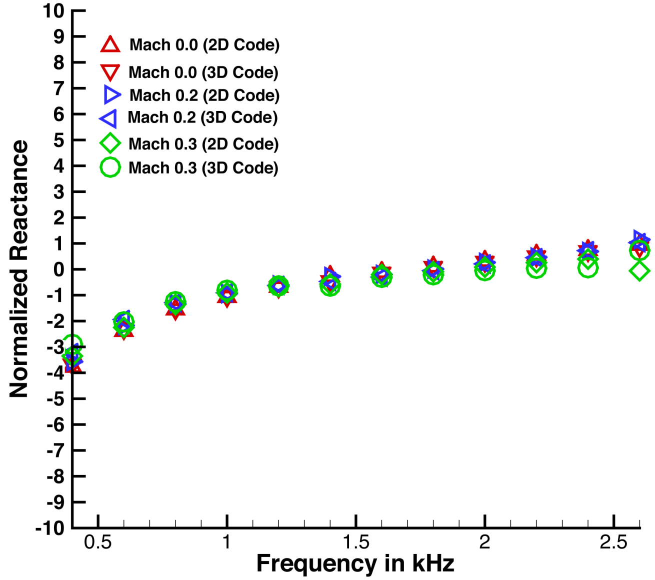
Comparison of SPL for Uniform and Segmented Liner at 800 Hz



Comparison of SPL for Uniform and Segmented Liner at 1,400 Hz




Mach 0.0 (2D Code)
Mach 0.0 (3D Code)
Mach 0.2 (2D Code)
Mach 0.2 (3D Code)
Mach 0.3 (2D Code)
Mach 0.3 (3D Code)
Normalized Resistance
Frequency in kHz
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.5
1
1.5
2
2.5



Normalized Reactance
Frequency in kHz
Mach 0.0 (2D Code)
Mach 0.0 (3D Code)
Mach 0.2 (2D Code)
Mach 0.2 (3D Code)
Mach 0.3 (2D Code)
Mach 0.3 (3D Code)